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Models for Estimating Research and Development Manpower in Navy Laboratories

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This report describes the development and implementation of models that project scientist, engineer, and technician (SE&T) staffing levels at each of the Commander, Space and Naval Warfare Systems Command research and development (R&D) centers by type of funds and product area, given specific funding levels and in-house/contract mixes. The model can also be used to evaluate the impacts of personnel ceiling and in-house dollar expenditure limits. The results should be of interest to defense R&D managers concerned with matching workload with work force.

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FOREWORD

This project was conducted in response to a Commander, Space and Naval Warfare Systems Command (SPAWAR-005) (formerly Director of Navy Laboratories) request to develop a Manpower Estimating Model (MEM) to estimate direct-funded Scientist, Engineer, and Technician (SE&T) staffing levels for the SPAWAR Research and Development (R&D) Centers. This report describes the development and implementation of models that forecast SE&T levels at the SPAWAR R&D Centers given specific funding levels and in-house/contract mixes. The models can also be used to evaluate the impact of personnel ceiling and in-house dollar expenditure limits. The results should be of interest to managers concerned with matching workload with work force and developing staffing controls for direct R&D functions.

Support in software development was provided by Mathematics Policy Research, Inc. under subcontract to Mathtech, Inc. of Falls Church, Virginia, under contract N00123-83-D-0520. The contracting officer's technical representative was Mr. Michael R. Shoecraft.

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SUMMARY

Problem

The Navy Research and Development (R&D) Centers employ a large quantity of highly trained and expensive manpower. Historically, the R&D centers have had difficulty in justifying their manpower requirements to higher authority. The nature of R&D is not amenable to traditional work measurement methodology such as engineered time standards, and there have been no methods available to match workload with staffing.

Objective

The primary objective of this effort was to develop Manpower Estimating Models (MEM) for total direct-funded scientist, engineer, and technician (SE&T) staffing levels for each of the Commander, Space and Naval Warfare Systems Command (SPAWAR) R&D Centers. The secondary objective was to provide SPAWAR financial managers with a budget and manpower justification tool.

Approach

The Navy Personnel R&D Center developed an aggregate level MEM for all of the SPAWAR R&D Centers in 1986. However, to satisfy the Navy Manpower Engineering Program requirements, MEMs needed to be developed for each R&D Center. Data was collected from the SPAWAR financial data base, the Project Listing. Multiple linear regression analysis was then used to develop MEMs that were both statistically sound and intuitively satisfying.

Results

The MEMs selected have two major variables, funding expended in-house and funding expended on contract. Variables representing product area and type of funds were also included. The MEMs mathematically relate aggregate measures of workload to manpower requirements.

The MEMs were implemented on an IBM XT microcomputer. The design allows the user to change input parameters, such as total funding and percentage of in-house funding, for "what if" analysis. The user can also constrain total work years and reallocate work years and in-house/contract mix across type of funds.

Conclusions

The MEMs met the primary objective of forecasting staffing requirements for the SPAWAR R&D Centers. Besides changing policy variables and projecting the effects on direct and total work years, SPAWAR financial managers can also use the system to analyze the impacts of personnel ceiling and in-house dollar expenditure limits. To remain useful, the MEM's should be revised each year with current project listing data.

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INTRODUCTION

Problem

The Navy's Research and Development (R&D) Centers employ a large quantity of technically trained and expensive manpower. Historically, the R&D centers have had difficulty in justifying their manpower requirements to higher authority. This is because the nature of R&D is not amenable to traditional work measurement methods such as engineered time standards. In addition, a model for each R&D center was needed to satisfy requirements of the Navy Manpower Engineering Program (NAVMEP) to relate manpower requirements to measures of workload at naval shore activities.

Objective

The primary objective of this effort was to develop Manpower Estimating Models (MEM) to project total direct-funded scientist, engineer, and technician (SE&T) staffing levels for each of the Commander, Space and Naval Warfare Systems Command (SPAWAR) R&D Centers. The secondary objective was to provide SPAWAR financial managers with a budget and manpower justification tool.

Background

An aggregate-level model, developed by Navy Personnel Research and Development Center (NPRDC), projects total SE&T staffing levels for the SPAWAR R&D Centers, by product area.[1] The independent variables are total funding level and in-house/contract mix. Product area is defined in NPRDC TR 87-2. The aggregate model can also be used to evaluate the impact of personnel ceiling and in-house dollar expenditure limits. This model satisfied the NAVMEP MEM requirement on an interim basis until individual models for each R&D center were developed. Development of individual models for each R&D center ensured that staffing coverage requirements for the SPAWAR R&D centers in the Navy Engineering Program would be met.

The eight SPAWAR R&D Centers for which MEMs were developed are the David W. Taylor Naval Ship R&D Center (DTNSRDC), Carderock and Annapolis, Maryland; Navy Surface Weapons Center (NSWC), Dahlgren, Virginia and White Oak Maryland; Navy Weapons Center (NWC) China Lake, California; Naval Coastal Systems Center (NCSC), Panama City, Florida; Naval Air Development Center, (NADC) Warminster, Pennsylvania; Naval Ocean Systems Center (NOSC), San Diego, California; Navy Personnel R&D Center (NPRDC), San Diego, California;[2] and Naval Undersea Systems Center, (NUSC), Newport, Rhode Island, and New London, Connecticut.

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[1] Medearis, B. D. (October 1986). A model for estimating direct funded civilian scientist, engineer, and technician staffing in the Navy research and development center (NPRDC TR 87-2). San Diego: Navy Personnel Research and Development Center.

[2] NPRDC, a SPAWAR R&D Center at the time this project was conducted, currently reports to the Chief of Naval Operations (OP-01).

APPROACH

Data Source

The primary data source used to develop the MEM's is the SPAWAR financial data base called the Project Listing. The Project Listing is maintained on the UNIVAC 1100 computer at the Naval Undersea Systems Center in New London, Connecticut and reports funding and work year information at the project and type of funds level for each of the SPAWAR R&D Centers. The Project Listing was available for FY78 through FY86. However, product area identification was not included until FY84.

Preliminary Data Analysis

A preliminary data analysis was performed to identify the most descriptive data and variables for the R&D centers. The unique workload of each R&D center made it necessary to develop individual models for each R&D center.

Exploratory data analysis was used to determine the most representative years in the data base for each R&D center. FY84 and FY85 were used for NOSC, NSWC, DTNSRDC, NUSC, and NCSC because data analysis revealed that product area terms were significant. For NADC, only FY85 data were used at their request. For NPRDC, FY78 data through FY85 data were used to have sufficient data to develop equations. NPRDC has only one product area, personnel and training. For NSWC, data for FY78 through FY85 were also used at their request.

Regression Analysis

In the regression analysis of the Project Listing Data, the significant variables were funding expended in-house, funding expended on contract, product area, and type of funds. Funding expended in-house and funding expended on contract were common for all of the R&D centers. The other variables, product areas and type of funds were applicable to some R&D centers and not others. Variables for funding expended in-house and funding expended on contract are consistent with previous work. Additionally, it seemed intuitively satisfying that the diverse product areas and type of funds of the R&D centers require varying degrees of labor intensity. Table 1 presents the definition of type of funds. Product areas are defined in NPRDC TR 87-2 and listed in Appendix A.

RESULTS

Models

The basic model formulation was:

$$WYR = a + b(IHD) + c(CTRD)$$

Where,

WYR = direct work years;
IHD = funding expended in-house (millions of 1980 $'s); and
CTRD = contracting out funds (millions of 1980 $'s)

Table 1

Type of Funds Definitions

Type Funds	Description
A	Navy Tech Base 6.1, 6.2, and 6.3a RDT&E,N
B	Navy Systems Development 6.3b, 6.4, 6.5 RDT&E,N
C	All other funding O&M,N, OPN, SCN, WPN, other military service, DoD and other federal agency funding.

Various diagnostic procedures were used to investigate combinations of dummy intercept and interaction variables for each R&D center. The models developed from regression analysis are shown in Table 2. Table 2 includes a summary of the models for each R&D center. For reference purposes it also includes the aggregate model described in NPRDC TR 87-2. Details of the models for each R&D center are provided in Appendix B.

Validation

The MEM's were validated by a comparison of computed direct work years to known values. For NOSC, NSWC, DTNSRDC, NUSC, and NCSC, the models were used to backcast FY83. For NADC, the model was used to backcast FY84. For NPRDC and NSWC, FY85 data was set aside and the model coefficients were re-estimated using FY78 through FY84 data. FY85 work years were re-estimated using this new model and compared to the reported work years for FY85. A summary of validation results for each model is given in Table 3.

The models were also used to predict work years for FY86. This model prediction was then compared to R&D center submitted projections for FY86. Table 4 summarizes the projection comparisons for each R&D center.

Implementation

The MEM's are implemented on an IBM XT microcomputer. The software is divided into three modules: the down load and update module, the planning module and the allocation module.

The down load and update module allows the user to review all of the data in the program. Also, this module permits data loading and permanent revisions to be made to the historical and planning data. These data form the initial values of the variables that are labeled "Base-Line" in the other modules.

Table 2

Model Summary

	Coefficients				Other Dimensions			
Activity	Data	N	IHD	OHD	Type Funds	Product Area	R^2	CV
NOSC	84-85	68	9.07	.62		X	99.8	7.03
NWC	84-85	22	7.04	1.12	X	X	98.0	12.95
DTNSRDC	84-85	30	10.63	1.90	X	X	98.7	12.88
NUSC	84-85	89	9.3	.93	X	X	98.8	11.62
NADC	85	53	11.80	.38			99.9	4.22
NCSC	84-85	43	12.32	.42	X	X	99.5	11.11
NPRDC	78-85	24	14.72	.82			96.3	13.52
NSWC	78-85	24	12.96	.51			95.8	8.22
AGGREGATE	80-84	190	10.57	.70		X	98.0	11.30

Table 3

Validation Results

		Work Years			Percent
Activity	Year	Model	Actual	Difference	Difference
NOSC	FY83	1441.9	1527.6	-85.7	-5.6
NWC	FY83	2438.0	2439.7	-1.7	-0.0
DTNSRDC	FY83	1522.4	1462.3	+60.1	+4.1
NUSC	FY83	1650.4	165.3	-0.9	-0.0
NADC	FY84	1433.5	1487.2	-53.7	-3.6
NCSC	FY83	411.5	406.9	+4.6	+1.1
NSWC	FY85	3100.3	3024.8	+75.5	+2.5
NPRDC	FY85	210.9	183.7	+27.5	+14.8

Table 4

FY86 Work Year Projection Comparisons

Activity	Work Years		Difference	Percent Difference
	Model	Lab Submission		
NOSC	2300.4	2008.8	+291.5	+12.7
NWC	3198.3	3237.6	-39.3	+1.2
DTNSRDC	1870.0	1792.8	+77.2	+4.3
NUSC	2094.1	2073.3	+20.8	+1.0
NADC	1739.2	1710.8	+28.4	+1.7
NCSC	653.9	718.7	-64.8	-9.0
NSWC	2582.0	3098.4	-516.4	-16.7
NPRDC	178.9	183.3	-4.4	-2.4

The planning module has two operating modes:

- Comparison Mode
- Scenario Mode

In the comparison mode, model computed Base-Line data for direct and total work years values satisfy the NAVMEP MEM requirement. A comparison to R&D center submitted values serves as a "reality check" on the budget submissions. It gives comparisons of model computed work years and R&D center submitted work years for direct-funded scientists, engineers, and technicians. It also provides comparisons of model estimated and R&D center submitted total work years.

In the scenario mode, model-computed Base-Line work years are compared to work years resulting from user-defined scenarios. These scenarios can reflect user-specified changes to the following variables.

- Funding levels
- Inflation rate (CPI)
- Mix of in-house/contract funding
- R&D center direct-to-total labor rates

The third module is the Allocation Module. It is used to examine the relationship between in-house funding and contract funding in cases where both total funding and total work years are constrained. The following data may be changed in the Allocation Module:

- Total funds
- Total and direct work years
- Direct-to-total labor rates
- Inflation rate

CONCLUSION

The MEM's meet the primary objective of projecting total direct-funded SE&T staffing requirements for each of the SPAWAR R&D centers. Meeting this objective satisfies the congressionally-mandated Navy Manpower Engineering Program (NAVMEP) requirement on staffing controls for personnel performing R&D. However, annual updates are essential if the model is to remain representative.

SPAWAR financial managers can use the model in the budget justification and review process by changing policy variables: total funding, percent in-house funding, the inflation factor (CPI) and the ratio of direct-to-total work years. They also can use the model to analyze the impact of personnel ceiling constraints and in-house dollar expenditure limits.

APPENDIX A

PRODUCT AREAS

PRODUCT AREAS

Product Number	Product Area
10	**COMBAT SYSTEMS INTEGRATION**
11	Surface Combat Systems Integration
12	Subsurface Combat Systems Integration
13	Air Combat Systems Integration
14	Multiplatform Combat Systems Integration
20	**WEAPONRY**
21	Gun Systems
22	Missiles
23	Free Fall Weapons
24	Torpedoes
25	Mines
26	High Power Radiation Development
27	Explosives
28	Lauchers
29	Fire Control
30	**COUNTER MEASURES**
31	Electronic Warfare Systems
32	Undersea Counter Measures
40	**SPECIAL OPERATIONS SUPPORT**
41	Landing Force Equipment and Systems
42	Coastal/Special Warfare Support
50	**VEHICLES**
51	Surface Vehicles
52	Subsurface Vehicles
53	Naval Air Vehicles
54	Crew Equipment and Life Support
60	**SURVEILLANCE**
61	Acoustic Reconnaissance and Search
62	Electromagnetic Reconnaissance and Search
63	Special Sensors
64	Ocean Surveillance
70	**COMMAND SUPPORT**
71	Command and Control
72	Communications
73	Navigation

80	**GENERAL MISSION SUPPORT**
81	Logistics
82	Facilities
83	Personnel and Training
84	Diving, Salvage, and Ocean Engineering
85	Environmental Description, and Effects Prediction
90	**SPECIAL INTEREST**
91	Navy Strategic Systems
92	Space Systems and Technology
93	Major Range Development and Operation
94	Nuclear Weapons and Effects
95	Center Missions and Functions Support

APPENDIX B

DETAILED MODELS

NAVAL OCEAN SYSTEMS CENTER

MANPOWER ESTIMATING MODEL RESULTS
FY84-FY85 DATA

$$DWY = 9.07\ IHD + 0.62\ CTR + 22.01\ GEM - 32.90\ MRD + 15.00\ OCS - 9.24\ FRC + 1.03$$

where:

DWY = Direct Workyears
IHD = In-House Funding (Millions of 1980 $s)
CTR = Contract Funding (Millions of 1980 $s)
GEM = 1 for General Mission Product Area,
0 Otherwise
MRD = 1 for Major Range Product Area,
0 Otherwise
OCS = 1 for Ocean Surveillance Product Area,
0 Otherwise
FRC = 1 for Fire Control Product Area,
0 Otherwise

$R^2 = .9984$ CV = 7.03 N = 68

VALIDATION

FY83 Submitted Workyears	FY83 Model Computed Workyears	Error	Percent Error
1527.6	1441.9	-85.7	-5.6

FY86 PREDICTION

Lab Projection	Model Prediction	Error	Percent Error
2008.8	2300.4	+291.5	+12.7

NAVY PERSONNEL R&D CENTER

MANPOWER ESTIMATING MODEL RESULTS
FY78-FY85 DATA

DWY = 14.72 IHD + 0.82 CTR - 4.89

where:

DWY = Direct Workyears
IHD = In-House Funding (Millions of 1980 $s)
CTR = Contract Funding (Millions of 1980 $s)

R^2 = .9627 CV = 13.52 N = 24

VALIDATION

Type Funds	FY85 Submitted Workyears	FY85 Model Computed Workyears	Error	Percent Error
A	89.5	100.3	+10.8	+12.1
B	20.5	18.5	-2.0	-9.8
C	73.7	92.1	18.4	+25.0
Total	183.7	210.9	+27.2	+14.8

FY86 PREDICTION

Type Funds	Lab Projection	Model Prediction	Error	Percent Error
A	94.2	93.1	-1.1	-1.1
B	21.5	24.9	+3.4	+15.9
C	67.6	60.9	-6.7	-9.9
Total	183.3	178.9	-4.4	-2.4

NAVAL WEAPONS CENTER

MANPOWER ESTIMATING MODEL RESULTS
FY84 - FY85 DATA

LOW COST SEEKER IN "OTHER" TYPE FUNDS
MISSILES "OTHER" FY85 OBSERVATION SET ASIDE

Major Range Systems Development

DWY = 20.71IHD + 1.12CTR + 10.11

All Other Funding Groups and Product Areas

DWY = 7.04IHD + 1.12CTR + 10.11

where

DWY = Direct Workyears
IHD - In House Funding (millions of 1980 $s)
CTR = Contract Funding (millions of 1980 $s)

R^2 = .980 CV = 12.95 N = 22

VALIDATION

Type Funds	FY83 Submitted Workyears	FY83 Model Computer Workycars	Error	Percent Error
A	289.4	264.6	-24.8	-8.6
B	1115.3	1269.2	+153.9	+13.9
C	1035.0	904.2	-130.8	-12.6
Total	2439.7	2438.0	-1.7	-0.0

FY86 PREDICTION

Type Funds	Lab Projection	Model Prediction	Error	Percent Error
A	382.4	344.2	-38.2	-10.0
B	1133.2	1303.4	+170.2	+15.0
C	1722.0	1550.7	-171.3	-9.9
Total	3237.6	3198.3	-39.3	-1.2

DAVID W. TAYLOR NAVAL SHIP R&D CENTER

MANPOWER ESTIMATING MODEL RESULTS
FY84 - FY85 DATA

Navy Tech Base and Navy Systems Development

All product areas except sub surface vehicles (52)
DWY = 10.63 IHD + 1.90 CTR + 1.81

Sub surface vehicles (52)
DWY = 11.89 IHD + 1.90 CTR + 1.81

All Other Funding Groups

All product areas except sub surface vehicles (52)
DWY = 7.52 IHD + 1.90 CTR + 1.81

Sub surface vehicles (52)
DWY = 8.78 IHD + 1.90 CTR + 1.81

where:

DWY = Direct Workyears
IHD = In House Funding (Millions of 1980 $s)
CTR = Contract Funding (Millions of 1980 $s)

R^2 = .9870 CV = 12.88 N = 30

VALIDATION

Type Funds	FY83 Submitted Workyears	FY83 Model Computed Workyears	Error	Percent Error
A	424.8	504.5	+79.7	+18.8
B	559.6	645.3	+85.7	+15.3
C	477.9	372.6	-105.3	-22.0
Total	1462.3	1522.4	+60.1	+4.1

FY86 PREDICTION

Type Funds	Lab Projection	Model Prediction	Error	Percent Error
A	388.2	397.0	+8.8	+2.3
B	933.0	984.0	+51.0	+5.5
C	471.6	489.0	+17.4	+3.7
Total	1792.8	1870.0	+77.2	+4.3

NAVAL UNDERSEA SYSTEMS CENTER

MANPOWER ESTIMATING MODEL RESULTS
FY84-FY85 DATA

Navy Tech Base

DWY = 10.81 IHD + 0.93 CTR + 9.84 SBS
- 7.82 ACR + .87

Navy Systems Development

All Product Areas Except Major Range Development and Operation

DWY = 9.30 IHD + 0.93 CTR + 9.84 SBS
- 7.82 ACR + .87

Major Range Development and Operation

DWY = 2.81 IHD + 0.93 CTR + .87

All Other Funding Groups

DWY = 7.97 IHD + 0.93 CTR + 9.84 SBS
- 7.82 ACR + .87

where:

DWY = Direct Workyears
IHD = In House Funding (Millions of 1980 $s)
CTR = Contract Funding (Millions of 1980 $s)
SBS = 1 for Subsurface Combat Systems Integration,
0 otherwise
ACR = 1 for Acoustic Reconnaissance and Search,
0 otherwise

R^2 = .9883 CV = 11.62 N = 89

VALIDATION

Type Funds	FY83 Submitted Workyears	FY83 Model Computed Workyears	Error	Precent Error
A	167.1	173.5	+6.4	+3.8
B	688.3	635.3	-53.0	-7.7
C	795.9	841.6	+45.7	+5.7
Total	1651.3	1650.4	-0.9	-0.0

FY86 PREDICTION

Type Funds	Lab Projection	Model Prediction	Error	Percent Error
A	184.8	220.3	+35.5	+19.2
B	873.2	906.3	+33.1	+3.8
C	1015.3	967.5	-47.8	-4.7
Total	2073.3	2094.1	+20.8	+1.0

NAVAL AIR DEVELOPMENT CENTER

MANPOWER ESTIMATING MODEL RESULTS
FY85 DATA

DWY = 11.80 IHD + 0.38 CTR - 0.24

where:

DWY = Direct Workyears
IHD - In-House Funding (Millions of 1980 $s)
CTR = Contract Funding (Millions of 1980 $s)

R^2 = .9992 CV = 4.22 N = 53

VALIDATION

Type Funds	FY84 Submitted Workyears	FY84 Model Computed Workyears	Error	Percent Error
A	310.6	268.9	-41.7	-13.4
B	657.4	608.9	-48.5	-7.4
C	519.2	555.7	+36.5	+7.0
Total	1487.2	1433.5	-53.7	-3.6

FY86 PREDICTION

Type Funds	Lab Projection	Model Prediction	Error	Percent Error
A	305.2	302.0	-3.2	-1.1
B	784.4	803.7	+19.3	+2.5
C	621.2	633.5	+12.3	+2.0
Total	1710.8	1739.2	+28.4	+1.7

NAVAL COASTAL SYSTEMS CENTER

MANPOWER ESTIMATING MODEL RESULTS
FY84-FY85 DATA

NAVY TECH BASE

DWY = 12.32 IHD + .42 CHD + .09

ALL OTHER FUNDING GROUPS

DWY = 12.32 IHD + .42 CHD - 7.81 GEM + .09

where:

DWY = Direct Workyears
IHD = In-House Funding (Millions of 1980 $s)
CTR = Contract Funding (Millions of 1980 $s)
GEM = 1 for General Mission and Function Support,
0 Otherwise

R^2 = .9946 CV = 11.11 N = 43

VALIDATION

Type Funds	FY83 Submitted Workyears	FY83 Model Computed Workyears	Error	Percent Error
A	97.3	98.9	+1.6	+1.7
B	173.4	181.2	+7.8	+4.5
C	136.2	131.4	-4.8	-4.8
Total	406.9	411.5	+4.6	+1.1

FY86 PREDICTION

Type Funds	Lab Projection	Model Prediction	Error	Percent Error
A	221.2	194.1	-27.1	-12.2
B	319.9	276.3	-43.6	-43.6
C	177.6	183.5	+5.9	+3.3
Total	718.7	653.9	-64.8	-9.0

NAVAL SURFACE WEAPONS CENTER

MANPOWER ESTIMATING MODEL RESULTS
FY78 - FY85 DATA

DWY = 12.96 IHD + 0.51 CTR + 131.05

where;

DWY = Direct Workyears
IHD = In House Funding (Millions of 1980 $s)
CTR = Contract Funding (Millions of 1980 $s)

R^2 = .9583 CV = 8.22 N = 24

VALIDATION

Type Funds	FY85 Submitted Workyears	FY85 Model Computed Workyears	Error	Percent Error
A	429.6	438.9	+9.3	+2.2
B	1124.2	1173.7	+49.5	+4.4
C	1471.0	1487.7	+16.7	+1.1
Total	3024.8	3100.3	+75.5	+2.5

FY86 PREDICTION

Type Funds	Lab Projection	Model Prediction	Error	Percent Error
A	601.8	492.9	-108.9	-18.1
B	1145.0	948.8	-196.2	-17.1
C	1351.6	1140.3	-211.3	-15.6
Total	3098.4	2582.0	516.4	-16.7

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